

Confined Space Safety: HIRA and Implementation of Effective Control Measures

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Abstract

Confined spaces present a unique set of hazards due to their limited entry and exit points, poor ventilation, and potential presence of toxic or flammable substances. This project focuses on the systematic identification of hazards, risk assessment, and the implementation of effective control measures to enhance safety in confined space operations. The primary objective is to apply the Hazard Identification and Risk Assessment (HIRA) methodology to various confined space scenarios commonly encountered in industrial environments, such as tanks, silos, manholes, and underground chambers. Through site observations, incident report analysis, and worker interviews, key hazards such as oxygen deficiency, toxic gases, engulfment, heat stress, and mechanical entrapment are identified. Each hazard is then assessed using a risk matrix to determine the severity and likelihood of occurrence. Based on the HIRA findings, this project proposes a structured framework of control measures, including engineering controls (e.g., forced ventilation, gas detection systems), administrative controls (e.g., confined space entry permits, training programs), and the use of appropriate personal protective equipment (PPE). Special emphasis is placed on implementing a comprehensive Permit-to-Work (PTW) system and emergency rescue procedures. A case study approach is employed to evaluate the effectiveness of these control measures in a real-world confined space task. Performance indicators such as incident rates, compliance levels, and worker feedback are analyzed before and after implementing the control measures. The project concludes that a well-structured HIRA process, combined with multi-layered control strategies, significantly reduces the risk associated with confined space work. Recommendations are made for continuous improvement, including the integration of real-time monitoring technologies and periodic safety audits. This study aims to contribute to safer confined space practices and raise awareness among safety professionals, workers, and management teams.

Keywords: Confined Space Safety, Hazard Identification and Risk Assessment (HIRA), Permit-to-Work System (PTW), Risk Control Measures, Industrial Occupational Safety.

1. Introduction

Confined spaces are common in many industrial environments, including manufacturing plants, construction sites, utilities, and process industries. These spaces are characterized by limited entry and exit points, restricted natural ventilation, and are not designed for continuous human occupancy. Examples include storage tanks, silos, pipelines,

manholes, and underground chambers. Due to these characteristics, confined spaces present serious safety and health risks to workers, making them one of the most hazardous work environments. The hazards associated with confined space operations include oxygen deficiency or enrichment, accumulation of toxic or flammable gases, engulfment by liquids or

solids, mechanical and electrical hazards, and physical risks such as slips, trips, and heat stress. In many incidents, lack of hazard awareness, inadequate planning, and failure to follow safe work procedures significantly increase the likelihood of accidents. Confined space accidents often result in severe injuries or fatalities, not only to workers entering the space but also to untrained rescuers. To effectively manage these risks, a systematic and proactive safety approach is essential. Hazard Identification and Risk Assessment (HIRA) is a structured methodology used to identify potential hazards, evaluate their likelihood and severity, and prioritize risks for control. This project focuses on the application of HIRA to confined space operations and the implementation of effective control measures based on the hierarchy of controls. The study aims to enhance worker safety, ensure regulatory compliance, and promote a strong safety culture through planned and well-documented risk management practices [1-5].

2. Literature Review

Recent literature shows a growing emphasis on improving safety in confined space operations through advanced technologies, systematic risk management, and human-centered design. Carlos Miguel Iegli da Silva et al. (2025) conducted a comprehensive review of confined space safety in the petroleum industry, highlighting that while traditional control measures remain widely uniform, emerging alternatives such as robotics, IoT, wearable sensors, and remote monitoring offer significant potential to enhance safety. Cultural, economic, and regulatory barriers continue to limit their large-scale adoption. Mr. Ratan L. Sharma et al. (2025) explored IoT-based safety solutions for underground tunneling, emphasizing real-time monitoring, predictive maintenance, and automated emergency response. Their study demonstrated that IoT frameworks can transform safety management from reactive to proactive, provided challenges related to connectivity, power supply, sensor durability, and cybersecurity are addressed. Wahidi et al. (2025) focused on structural optimization in confined shipbuilding spaces, showing that reducing structural weight and welding requirements can significantly improve safety and reduce costs. Their work highlights the importance of integrating safety and

manufacturability considerations at the design stage and supports future automation and robotic welding applications. Evangelista et al. (2025) examined immersive virtual reality (IVR) training for confined spaces and found strong evidence of improved safety behavior, reduced errors, and enhanced learning outcomes. Studies by Wang et al. (2024) and Zhang et al. (2024) further contributed experimental and ergonomic perspectives, addressing gas diffusion risks and wearable safety design. Overall, the literature emphasizes that combining technological innovation with systematic risk assessment, training, and ergonomic design is essential for effective confined space safety management Shown in Figure 1.

3. Methodology

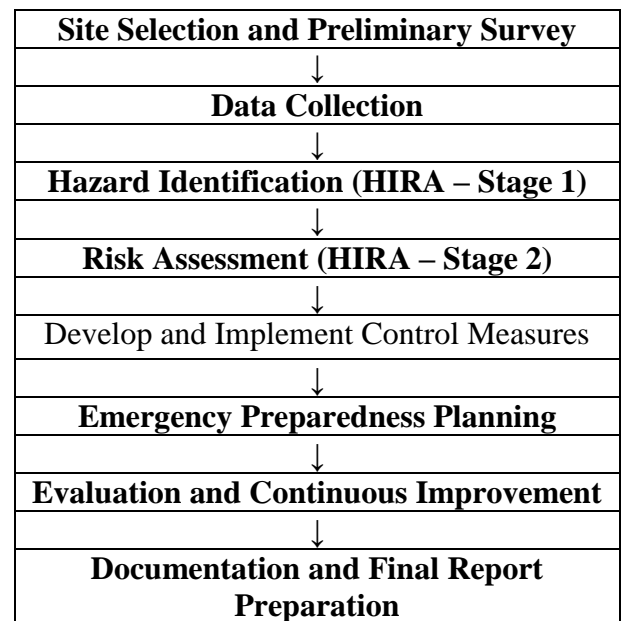


Figure 1 Methodology

3.1. Site Selection and Preliminary Survey

Site selection and preliminary survey form the foundation of an effective confined space safety assessment. Confined spaces are inherently hazardous due to limited access, poor ventilation, potential accumulation of toxic or flammable atmospheres, and the presence of mechanical and physical hazards. Selecting an appropriate site where confined space activities are routinely performed is essential to ensure that the Hazard Identification and Risk Assessment (HIRA) process reflects real

operational conditions rather than theoretical assumptions. The selected site must represent a variety of confined space scenarios and associated risks. Criteria for selection include the presence of different types of confined spaces such as tanks, vessels, manholes, or underground chambers; ongoing operational activities requiring confined space entry; a history of incidents or near misses; availability of safety equipment; and strong management commitment. These criteria ensure comprehensive hazard identification, realistic risk evaluation, and effective implementation of control measures. Based on these requirements, an industrial manufacturing plant was selected as the project site. The facility includes multiple confined spaces used for maintenance, inspection, and cleaning activities, exposing workers to atmospheric, mechanical, and physical hazards. A recent near-miss incident related to gas exposure further highlighted the need for a structured safety assessment. Importantly, site management demonstrated a proactive attitude toward safety improvement, granting access for inspections, data collection, and implementation of recommended controls. The preliminary survey involved systematic walkthrough inspections, observation of work practices, review of safety procedures and records, and discussions with workers and supervisors. This survey provided valuable insights into actual working conditions, existing safety controls, and gaps in compliance. Issues such as inconsistent atmospheric monitoring, variable enforcement of permit-to-work systems, training gaps, and emergency preparedness weaknesses were identified. Physical hazards including inadequate lighting and slippery surfaces were also observed. Overall, the site selection and preliminary survey ensured that the HIRA process was grounded in site-specific realities. This approach enabled accurate hazard identification and laid a strong foundation for developing targeted and effective control measures to enhance confined space safety [6-9].

3.2. Data Collection

Data collection is a crucial stage in the Hazard Identification and Risk Assessment (HIRA) process, as it provides reliable evidence for understanding confined space hazards, evaluating risk levels, and developing effective control measures. In this project,

a systematic and multi-source data collection approach was adopted to ensure accuracy, completeness, and relevance of information related to confined space safety. Multiple site visits were conducted to carry out detailed walkthrough inspections of confined spaces such as tanks, silos, manholes, and underground chambers. These inspections focused on physical conditions including access and egress arrangements, ventilation effectiveness, lighting adequacy, warning signage, and the availability and condition of safety equipment such as gas detectors, rescue systems, and personal protective equipment (PPE). Standardized confined space safety checklists were used to maintain consistency in observations and to identify gaps in existing controls and procedural compliance. Photographic evidence was also collected to document unsafe conditions and equipment deficiencies. In addition to observations, interviews were conducted with confined space workers, supervisors, safety officers, and maintenance personnel. These interactions provided valuable insights into perceived hazards, practical challenges during confined space entry, communication issues, and barriers to compliance with safety procedures. Such qualitative data helped identify behavioral and procedural risks not evident through inspections alone. Historical records, including incident reports, near-miss data, previous risk assessments, and training records, were reviewed to understand past failures, recurring hazards, and the effectiveness of existing safety management practices. Furthermore, confined spaces were classified based on type and activity, such as maintenance, cleaning, inspection, and repair work, recognizing that different tasks involve different risk profiles [10 - 12]. The integration of observational data, worker feedback, and historical records enabled a comprehensive understanding of atmospheric, physical, mechanical, and administrative hazards. This robust data collection phase formed a strong foundation for accurate risk assessment and the development of targeted, site-specific control measures to improve confined space safety Shown in Table 1 - 8.

Table 1 Confined Space Inventory and Site

Sl. No.	Parameter	Statistical Value
1	Total industrial sites surveyed	5 sites
2	Total confined spaces identified	42 units
3	Average confined spaces per site	8.4
4	Storage tanks	14 (33.3%)
5	Silos	9 (21.4%)
6	Manholes	11 (26.2%)
7	Underground chambers	8 (19.1%)
8	Vertical entry confined spaces	24 (57.1%)
9	Horizontal entry confined spaces	18 (42.9%)
10	Confined spaces with single entry	36 (85.7%)
11	Confined spaces with multiple entries	6 (14.3%)

Table 2 Workforce Exposure and Experience

Sl. No.	Parameter	Statistical Value
1	Total workers involved	96
2	Permanent workers	58 (60.4%)
3	Contract workers	38 (39.6%)
4	Average age of workers	34.6 years
5	Workers with >5 years' experience	29 (30.2%)
6	Workers with 1-5 years' experience	41 (42.7%)
7	Workers with <1 year experience	26 (27.1%)
8	Workers trained in confined space safety	44 (45.8%)
9	Workers untrained	52 (54.2%)

Table 3 Atmospheric Monitoring

Sl. No.	Parameter	Statistical Value
1	Oxygen level <19.5%	13 spaces (31.0%)

2	Oxygen level 19.5–23.5%	26 spaces (61.9%)
3	Oxygen level >23.5%	3 spaces (7.1%)
4	Confined spaces with toxic gas presence	17 (40.5%)
5	Average O ₂ concentration	20.1%
6	H ₂ S detected (ppm range)	3–42 ppm
7	CO detected (ppm range)	10–68 ppm
8	CH ₄ detected (% LEL)	12–38%
9	Spaces without continuous gas monitoring	26 (61.9%)
10	Spaces with fixed gas detectors	16 (38.1%)

Table 4 Physical and Environmental Hazard

Sl. No.	Hazard Type	Frequency / Value
1	Poor ventilation	29 spaces (69.0%)
2	Heat stress (>30°C)	18 spaces (42.9%)
3	Average temperature inside spaces	34.2°C
4	Relative humidity range	62–88%
5	Poor illumination (<100 lux)	22 spaces (52.4%)
6	Slippery / wet surfaces	14 spaces (33.3%)
7	Risk of engulfment	11 spaces (26.2%)

Table 5 Mechanical and Energy Hazard

Sl. No.	Parameter	Statistical Value
1	Confined spaces with moving equipment	16 (38.1%)
2	Improper lockout/tagout	19 cases (45.2%)

3	Mechanical entrapment risk	14 cases (33.3%)
4	Electrical installations inside spaces	10 (23.8%)
5	Energy isolation not verified	17 cases (40.5%)

Table 6 Administrative Controls and PTW

Sl. No.	Parameter	Statistical Value
1	Confined space entry permit used	21 cases (50.0%)
2	Permits fully compliant	9 cases (21.4%)
3	Permits partially compliant	12 cases (28.6%)
4	No permit system	9 cases (21.4%)
5	Pre-job toolbox talks conducted	18 cases (42.9%)
6	Job Safety Analysis performed	15 cases (35.7%)

Table 7 PPE Usage and Compliance

Sl. No.	PPE Type	Compliance Level
1	Safety helmet	88%
2	Safety shoes	82%
3	Respirators / gas masks	54%
4	Full body harness	47%
5	Portable gas detector	39%
6	Emergency escape breathing device	31%

Table 8 Incident and Near-Miss (Last 3 Years)

Sl. No.	Parameter	Statistical Value
1	Total confined space incidents	11
2	Fatal incidents	2

3	Serious injuries	5
4	Minor injuries	4
5	Incident rate (per 100 workers/year)	3.8
6	Reported near-miss cases	17
7	Estimated unreported near-misses	~40%

PPE Usage and Compliance: The PPE usage and compliance data highlight significant variations in adherence levels among workers involved in confined space operations. High compliance is observed for basic protective equipment such as safety helmets (88%) and safety shoes (82%), indicating good awareness of general safety requirements. However, compliance drops noticeably for task-specific and life-saving PPE. Respirators or gas masks show only 54% usage, which is concerning given the risk of toxic or oxygen-deficient atmospheres. Even lower compliance is seen for full body harnesses (47%), portable gas detectors (39%), and emergency escape breathing devices (31%), all of which are critical for confined space safety [13].

3.3. Hazard Identification (HIRA – Stage 1)

Hazard Identification is the first and most critical stage of the Hazard Identification and Risk Assessment (HIRA) process, forming the foundation for effective risk management in confined space operations. Confined spaces are inherently dangerous due to their restricted entry and exit, limited natural ventilation, and the potential presence of hazardous atmospheres, mechanical systems, and environmental stressors. If hazards are not identified comprehensively at this initial stage, subsequent risk evaluation and control measures may be incomplete or ineffective, significantly increasing the likelihood of accidents and fatalities. In confined space environments, hazards are often complex and interrelated. Atmospheric hazards such as oxygen deficiency, toxic gas accumulation, or flammable vapors may coexist with physical hazards like slippery surfaces, poor lighting, or extreme temperatures. Additionally, mechanical and electrical hazards from energized equipment, along with engulfment risks from loose materials or liquids, further elevate the danger. Human and procedural

factors, including inadequate training, poor supervision, and non-compliance with permit-to-work systems, can intensify these risks and contribute to unsafe conditions. The purpose of hazard identification at this stage is to systematically recognize and document all potential sources of harm that may affect workers during confined space entry, work, and exit activities. This process involves direct site observations, atmospheric testing, review of incident and near-miss records, and interaction with workers and supervisors. By adopting a structured and methodical approach, both obvious and hidden hazards can be identified, ensuring that no significant risk is overlooked. Hazard identification also helps in understanding the operational context of confined space activities. It highlights how environmental conditions, equipment, work processes, and human behavior interact to create risk. This holistic understanding is essential for developing targeted and effective control measures tailored to specific confined space scenarios. Ultimately, Stage 1 of HIRA provides a clear, actionable inventory of hazards, serving as the basis for risk assessment, prioritization, and implementation of appropriate control strategies to protect workers and ensure compliance with safety standards [14].

3.4. Risk Assessment (HIRA – Stage 2)

Risk Assessment is the second and most decisive stage of the Hazard Identification and Risk Assessment (HIRA) process, where the hazards identified in Stage 1 are systematically analyzed to determine their level of risk. In confined space operations, this stage is especially critical because even a single uncontrolled hazard can result in severe injury or fatality. Risk assessment converts qualitative hazard information into measurable risk levels, enabling informed decision-making and effective prioritization of control measures. The core objective of this stage is to evaluate each hazard based on two key parameters: likelihood and severity. Likelihood represents the probability of a hazardous event occurring during confined space entry or work, considering factors such as past incidents, frequency of exposure, environmental conditions, and the effectiveness of existing controls. Severity refers to the potential consequences if the hazard leads to an incident, ranging from minor injuries to catastrophic

outcomes such as permanent disability or death. For example, oxygen deficiency or toxic gas exposure carries very high severity due to life-threatening consequences, even if the likelihood is moderate. By combining likelihood and severity using a risk assessment matrix, each hazard is assigned a risk score and categorized as low, medium, high, or extreme risk. This structured approach ensures consistency and objectivity in risk evaluation. High and extreme risks, such as atmospheric hazards, engulfment, or delayed rescue due to poor communication, demand immediate attention and robust control measures. Medium risks, including heat stress or slips and trips, require planned interventions and continuous monitoring, while low risks are managed through routine controls and periodic review. Risk assessment also considers additional factors such as the number of workers exposed, duration of exposure, and reliability of existing safety systems. The results are documented clearly to support accountability, action planning, and future review. Overall, HIRA Stage 2 plays a vital role in transforming hazard data into prioritized safety actions, ensuring that confined space operations are managed proactively and risks are reduced to acceptable levels.

3.5. Develop and Implement Control Measures

After completing Hazard Identification (HIRA – Stage 1) and Risk Assessment (HIRA – Stage 2), the next critical step in confined space safety management is the development and implementation of effective control measures. Confined spaces inherently pose high risks due to restricted access, inadequate ventilation, and the possible presence of toxic, flammable, or oxygen-deficient atmospheres. Therefore, a structured and systematic approach is essential to reduce these risks to As Low As Reasonably Practicable (ALARP). The development of control measures is guided by the Hierarchy of Controls, which prioritizes risk reduction strategies based on their effectiveness. Elimination is the most effective control and involves removing the need for confined space entry altogether. This is achieved through task redesign, automation, and the use of remote inspection technologies such as CCTV systems, drones, or robotic devices. Where elimination is not feasible, substitution is applied by

replacing hazardous substances, processes, or equipment with safer alternatives, such as low-toxicity or non-flammable materials. Engineering controls form the backbone of confined space risk mitigation. These include forced ventilation systems to maintain safe atmospheric conditions, continuous gas monitoring to detect hazardous gases in real time, isolation of energy sources through lockout/tagout procedures, and safe access arrangements such as ladders, platforms, and adequate lighting. These controls physically separate workers from hazards and provide continuous protection. Administrative controls complement engineering measures by standardizing safe work practices. Permit-to-Work (PTW) systems, standard operating procedures (SOPs), defined roles and responsibilities, supervision, training, and emergency preparedness plans ensure consistent and disciplined execution of confined space activities. Personal Protective Equipment (PPE) serves as the final layer of protection, including respiratory protection, harnesses, protective clothing, helmets, and communication devices. The effectiveness of control measures depends on proper implementation, worker competency, continuous monitoring, and periodic review. Regular audits, training updates, and post-implementation risk reassessment ensure sustained safety performance. Overall, a multi-layered control strategy aligned with the Hierarchy of Controls significantly reduces confined space risks, enhances regulatory compliance, and protects workers from serious injuries and fatalities Shown in Table 9.

3.6. Emergency Preparedness Planning

Emergency Preparedness Planning is a vital pillar of confined space safety management, as incidents in confined spaces can escalate rapidly due to restricted access, hazardous atmospheres, and limited rescue options. Even minor deviations from normal operating conditions may lead to life-threatening situations if effective emergency arrangements are not in place. Therefore, a proactive, well-structured emergency preparedness plan is essential to protect workers, minimize response time, and reduce the severity of injuries or fatalities. As confined space safety programs evolve, future efforts must emphasize site-specific and hazard-focused emergency planning. Each confined space has unique

characteristics such as geometry, access points, atmospheric risks, and process-related hazards. Emergency preparedness planning begins with the identification and evaluation of credible emergency scenarios using HIRA findings, historical incidents, and near-miss data. This ensures that emergency response plans are realistic, relevant, and aligned with actual operational risks rather than generic assumptions. A key component of effective preparedness is the development of a documented Emergency Response Plan (ERP) that clearly defines roles, responsibilities, communication protocols, and escalation procedures. The ERP must specify appropriate rescue strategies—self-rescue, non-entry rescue, or entry rescue—based on confined space classification and rescue complexity. Priority should always be given to non-entry rescue methods to minimize rescuer exposure and secondary casualties. Regular training and competency development are essential to ensure that workers, supervisors, attendants, and rescue teams can respond effectively under emergency conditions. Periodic mock drills and simulated rescue exercises help test response times, coordination, and decision-making, while also identifying gaps in procedures, equipment, or communication systems. Lessons learned from drills and real incidents must be systematically documented and incorporated into revised emergency plans. Integration with external emergency services such as fire brigades and medical teams further strengthens preparedness, particularly for high-risk or complex confined spaces. Continuous evaluation, performance review, and comprehensive documentation ensure regulatory compliance and drive continuous improvement. Overall, robust emergency preparedness planning significantly enhances confined space safety performance and strengthens organizational safety culture [15].

3.7. Evaluation and Continuous Improvement

Evaluation and Continuous Improvement form the backbone of a sustainable confined space safety management system. While hazard identification, risk assessment, and the implementation of control measures significantly reduce risks, their effectiveness may decline over time due to changes in operating conditions, equipment aging, workforce turnover, and evolving regulatory requirements.

Therefore, continuous evaluation is essential to ensure that safety controls remain effective, relevant, and aligned with actual workplace conditions. A structured evaluation process involves ongoing performance monitoring through safety audits, inspections, and data analysis. Key safety indicators such as permit compliance, gas monitoring results, near-miss reports, and emergency drill performance provide measurable insight into system effectiveness. The use of real-time data from gas detectors, wearable devices, and digital permit-to-work systems enables early detection of deviations in atmospheric conditions or unsafe practices, allowing prompt corrective action before incidents occur. Worker feedback is a critical component of continuous improvement. Frontline employees possess practical knowledge of confined space challenges and can

identify gaps that may not be visible through audits alone. Safety meetings, toolbox talks, surveys, and anonymous reporting systems encourage open communication and near-miss reporting, fostering a proactive safety culture focused on prevention rather than blame. Incident and near-miss investigations using root cause analysis techniques further support learning and prevent recurrence. Benchmarking against industry standards, regulatory requirements, and best practices helps organizations measure their safety performance and identify areas for enhancement. Integrating technological advancements such as advanced gas sensors, automated monitoring, and data analytics strengthens hazard control reliability and responsiveness.

Table 9 Framework for Evaluation and Continuous Improvement

Step No.	Stage	Description	Key Activities	Purpose / Outcome
Step 1	Performance Monitoring	Continuous observation of safety performance	Track incidents, near misses, gas levels, permit compliance	Early detection of deviations
Step 2	Safety Audits and Inspections	Systematic review of confined space controls	Internal and external audits, inspections	Verify effectiveness of controls
Step 3	Data Collection and Analysis	Use qualitative and quantitative data	Sensor data, inspection records, reports	Identify trends and patterns
Step 4	Worker Feedback Mechanisms	Capture frontline experience	Safety meetings, surveys, interviews	Identify practical issues
Step 5	Incident and Near-Miss Review	Analyze failures and close calls	Root cause analysis (RCA)	Prevent recurrence
Step 6	Performance Benchmarking	Compare with best practices and standards	Industry data, regulatory benchmarks	Identify improvement gaps
Step 7	Corrective and Preventive Actions	Address identified deficiencies	Engineering upgrades, procedural changes	Risk reduction

Step 8	Management Review	Leadership evaluation of system performance	Review KPIs and audit results	Strategic oversight
Step 9	System Update and Integration	Update procedures and controls	Revise SOPs, training modules	Maintain relevance
Step 10	Continuous Learning Cycle	Institutionalize lessons learned	Knowledge sharing and training	Sustainable improvement

Management review plays a vital role in sustaining continuous improvement. Leadership evaluation of safety performance, audit outcomes, and corrective action effectiveness ensures accountability, resource allocation, and strategic alignment. By embedding evaluation and continuous improvement into daily operations and decision-making processes, organizations can continuously refine confined space safety programs. This proactive approach not only reduces incidents and fatalities but also enhances regulatory compliance, operational efficiency, and long-term organizational resilience.

3.8. Documentation and Final Report Preparation

Documentation and Final Report Preparation are critical components of effective confined space safety management, ensuring transparency, accountability, and regulatory compliance. Comprehensive documentation captures every stage of the safety process, including hazard identification, risk assessment, implementation of control measures, emergency preparedness, training activities, and incident investigations. Maintaining accurate and well-organized records enables traceability of risks and controls, supports audits and inspections, and demonstrates compliance with statutory and organizational requirements. The preparation of a structured final report consolidates all safety-related findings, actions taken, and performance outcomes into a clear and accessible format for management, safety professionals, and regulatory authorities. These reports facilitate informed decision-making, management review, and effective communication of safety performance. Additionally, final reports serve as valuable reference documents for future projects, continuous improvement initiatives, and training

programs. By integrating thorough documentation with emergency preparedness planning and continuous evaluation, organizations can build on existing safety achievements, reduce confined space risks, and strengthen long-term safety performance and compliance.

4. Result and Discussion

This section presents the results obtained from the application of the Hazard Identification and Risk Assessment (HIRA) methodology and discusses the effectiveness of the implemented control measures in confined space operations. The findings are based on site observations, risk assessment outcomes, implementation of control strategies, and evaluation of key performance indicators (KPIs) before and after intervention.

4.1. Results of Hazard Identification (HIRA – Stage 1)

The hazard identification process revealed that confined space operations are associated with multiple high-risk hazards due to limited ventilation, restricted movement, and the potential presence of hazardous substances. Atmospheric hazards were identified as the most critical, particularly oxygen deficiency and the presence of toxic gases such as hydrogen sulfide (H₂S) and carbon monoxide (CO). These hazards were commonly observed in tanks, underground chambers, and manholes, especially where organic decomposition or chemical residues were present. Physical hazards such as slips, trips, and falls were also frequently identified due to uneven surfaces, poor lighting, and moisture accumulation. Mechanical hazards, including entrapment from moving parts and unexpected energization of equipment, were observed in confined spaces involving mixers, agitators, and

conveyors. Human and procedural hazards, such as inadequate training, poor communication, and non-compliance with permit-to-work procedures, further increased overall risk exposure.

4.2. Results of Risk Assessment (HIRA – Stage 2)

Risk assessment using the likelihood–severity matrix classified the identified hazards into low, medium, and high-risk categories. Atmospheric hazards consistently scored high risk due to their severe consequences and moderate likelihood of occurrence. Oxygen deficiency and toxic gas exposure recorded the highest risk scores, indicating the potential for fatal outcomes if control measures were absent or ineffective. Mechanical entrapment and engulfment hazards were categorized as medium to high risk, depending on task frequency and equipment isolation practices. Heat stress and physical hazards such as slips and falls were predominantly classified as medium risk, as their severity was moderate but likelihood increased during prolonged work durations. Low-risk hazards were limited and generally associated with minor ergonomic or housekeeping issues. The risk prioritization process enabled focused allocation of resources toward high-risk hazards, ensuring that critical issues were addressed first.

4.3. Results of Control Measure Implementation

The implementation of control measures based on the Hierarchy of Controls led to a significant reduction in overall risk levels. Engineering controls, particularly forced ventilation systems and continuous gas monitoring, proved to be the most effective interventions. Atmospheric testing before entry and real-time gas detection during work resulted in early identification of unsafe conditions, preventing exposure-related incidents. Administrative controls, including the introduction of a structured Permit-to-Work (PTW) system, standardized operating procedures (SOPs), and mandatory training programs, improved compliance and procedural discipline. The PTW system ensured that hazards were reviewed before each entry and that rescue arrangements were verified, significantly reducing unsafe entries. The use of appropriate PPE, such as respirators, harnesses, and protective clothing,

provided an additional layer of protection where hazards could not be fully eliminated. While PPE alone was insufficient to control risks, its integration with higher-level controls enhanced overall safety performance.

4.4. Emergency Preparedness and Response Outcomes

Emergency preparedness planning resulted in improved response readiness. Rescue drills demonstrated better coordination among workers, attendants, and supervisors, with noticeable reductions in response time during simulated emergencies. The availability and proper maintenance of rescue equipment, including retrieval systems and breathing apparatus, increased confidence among workers and supervisors regarding emergency handling. Worker feedback indicated improved awareness of emergency procedures and a clearer understanding of individual roles during rescue operations. This contributed to a stronger safety culture and reduced hesitation in reporting unsafe conditions.

4.5. Evaluation of Key Performance Indicators

Comparative analysis of key performance indicators before and after implementation showed measurable improvements. Incident and near-miss rates related to confined space operations decreased significantly following control implementation. Compliance levels with PTW procedures and safety checks improved due to enhanced supervision and training. Worker feedback surveys reflected increased confidence in safety systems and a better understanding of confined space hazards. These improvements confirm the effectiveness of a structured HIRA-based approach combined with multi-layered control strategies. The results clearly demonstrate that confined space risks cannot be effectively managed through isolated controls. Instead, a systematic approach integrating hazard identification, risk assessment, engineering controls, administrative procedures, PPE, and emergency preparedness is essential. Atmospheric hazards remain the most critical risk factor, reinforcing the importance of ventilation and continuous monitoring. The study highlights that administrative failures, such as inadequate training or poor permit implementation, can undermine even well-designed engineering controls. Therefore,

management commitment and worker participation are crucial for sustained safety performance. The findings also emphasize the importance of continuous evaluation and documentation. Regular audits, monitoring data, and feedback mechanisms ensure that control measures remain effective under changing operational conditions. Overall, the implementation of HIRA and effective control measures resulted in a substantial reduction in risk levels and improved safety outcomes in confined space operations. The results validate that a structured, proactive safety management approach significantly enhances worker protection, regulatory compliance, and operational reliability.

Conclusion

Confined space operations present significant occupational safety challenges due to restricted access, poor ventilation, and the potential presence of hazardous atmospheres and physical dangers. This project successfully demonstrated the effectiveness of a structured and systematic approach to managing these risks through the application of the Hazard Identification and Risk Assessment (HIRA) methodology. The study systematically identified a wide range of hazards commonly associated with confined spaces, including atmospheric hazards such as oxygen deficiency and toxic gas accumulation, physical hazards like slips, trips, and falls, mechanical and electrical risks, engulfment hazards, and human or procedural failures. The subsequent risk assessment process, based on likelihood and severity evaluation, enabled clear classification and prioritization of hazards into low, medium, and high-risk categories. This prioritization ensured that critical hazards were addressed promptly and resources were allocated efficiently. The implementation of control measures following the Hierarchy of Controls proved highly effective in reducing overall risk levels. Engineering controls such as forced ventilation systems, continuous gas monitoring, and isolation of energy sources significantly improved the safety of confined space environments. Administrative controls, including a robust Permit-to-Work system, standard operating procedures, and competency-based training, strengthened compliance and accountability. Personal protective equipment served as an essential

supplementary safeguard, particularly during high-risk activities. Emergency preparedness planning further enhanced safety outcomes by improving response readiness, coordination, and rescue effectiveness. Regular drills and the availability of trained rescue personnel and equipment contributed to a proactive safety culture and reduced the potential severity of incidents. Overall, the findings confirm that a well-structured HIRA process combined with multi-layered control measures significantly minimizes risks in confined space operations. Continuous evaluation, documentation, and adoption of advanced monitoring technologies are essential to sustain and improve safety performance. This project reinforces the importance of proactive risk management and provides a practical framework that can be applied across various industrial sectors to enhance confined space safety and protect worker health and life.

References

- [1]. Carlos Miguel Iegli da Silva, Fernando Gonçalves Amaral, Study on safely working in confined spaces in the petroleum industry: Risk factors, current control procedures, and alternatives, 2025.
- [2]. Mr. Ratan L. Sharma, Iot-Based Safety Solutions for Underground Tunneling: Constraints and Mitigation Strategies. 2025.
- [3]. Sufian Imam Wahidi, Selda Oterkus, Erkan Oterkus, Structural optimisation for minimising weight and welding in confined shipbuilding spaces: Enhancing safety and reducing costs. 2025.
- [4]. Alessandro Evangelista, Vito M. Manghisi, Vito De Giglio, From knowledge to action: Assessing the effectiveness of immersive virtual reality training on safety behaviors in confined spaces using the Kirkpatrick model, 2025.
- [5]. Xuemei Wanga, Tianlai Houa, Wenxue Gao, Experimental study on the diffusion process of natural gas from buried pipelines to underground confined spaces, 2024.
- [6]. Fanglan Zhang, Xin Li, Shizhao Xu, Ergonomic design of safety protective wearables in confined space operations, 2024.
- [7]. Kadir Arifin, Mohd Akhir Ahmad, Systematic

- literature review: Characteristics of confined space hazards in the construction sector, 2023
- [8]. W. Boulefaa, T. Autret, T.H. Benchekroun, Mobilize organizational arbitrations to prevent occupational risks in confined spaces: the case of sewer pipe rehabilitation projects, 26 (2020) 19–44.
- [9]. Chiu C. chen, Chang Y. ming, Wan T. jou. Characteristic Analysis of Occupational Confined Space Accidents in China and Its Prevention Strategy. 2020;1–13.
- [10]. L. Di Donato, F. Longo, A. Ferraro, M. Pirozzi, An advanced solutions for operators' training working in confined and /or pollution suspected space, *Procedia Manufacturing*, Elsevier B.V, 2020, pp. 254–258.
- [11]. Fithri P., Wirdianto E., Octaviani Y. Risk assesment in confined space of the ship repair at PT Bandar Abadi Ship Builders and Risk Assesment in Confined Space of The Ship Repair at PT Bandar Abadi Ship Builders and Dry-Docks. 2020;040001(May).
- [12]. Z.A. Kiehl, K.T. Durkee, K.C. Halverson, J.C. Christensen, G.F. Hellstern, Transforming work through human sensing: a confined space monitoring application, *Struct. Health Monit.* 19 (1) (2020) 186–201.
- [13]. Landucci G., Ricciardi L., Rossi L., Ovidi F. Quantitative Methodology to Support the Hazard Assessment of Confined Space Operations in the Process Industry. 82(December 2019):2020;1–6.
- [14]. Dowd D., Daher E. Redefining confined space safety: a case study, 2019.
- [15]. K.Z. Naghavi, S.B. Mortazavi, M.H.A. Hajizadeh, E. Exploring the contributory factors of confined space accidents using accident investigation reports and semistructured interviews, *Saf. Health Work* [Internet] 10 (3) (2019) 305–313, <https://doi.org/10.1016/j.shaw.2019.06.007>.